PARTICLE
TJC: ~~A~~ STORY FOR THE GAL. CENTER. EXT. $\gamma$ RAY EMS. 7 FEB 2014

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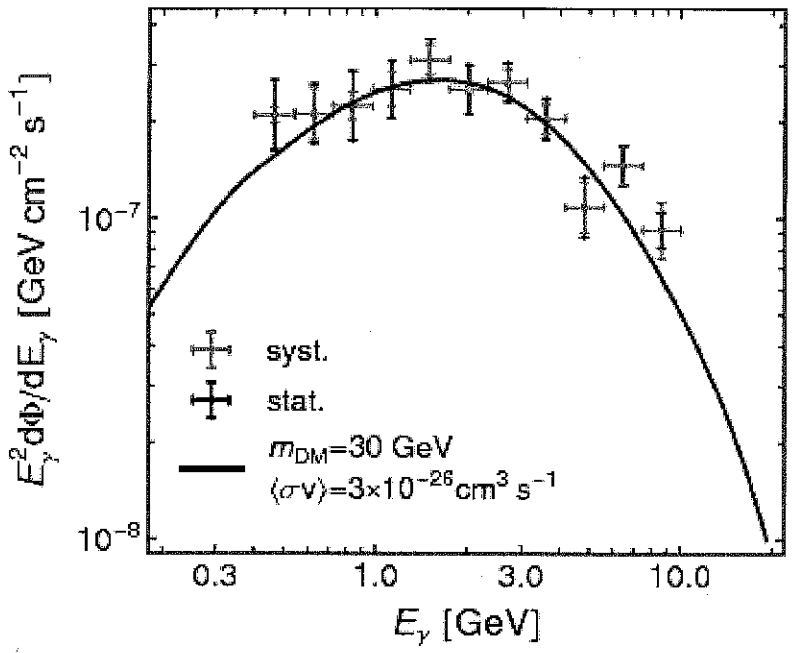
PRESENTING : 1401.6458

↗ advertise monthly "inter group" theme

The astro story: [SIMONA WILL GIVE INDIRECT DET. OVERVIEW IN A FEW WEEKS]




FROM: GORDON 2013

(KEV, MANOJ, NIC, SHUNSAKU HAVE NEW PAPER SOON)

↑ extended $\gamma$ ray excess in 7°×7° ← TRACEY LOOKS JUST OFF CENTER region centered @ G.C.

FIT: 30 GeV DM ANNIHILATE TO $b\bar{b}$


} if these have 30 GeV, then they emit a spectrum of $\gamma$ that fits data

CAVEAT: BACKGROUND SUBTRACTION IS NON-TRIVIAL
MANY THINGS TO FIT... & THIS IS VERY TRICKY
⇓
as everyone else in this room knows better than me!

CAN ALSO FIT W/ 10 GeV → $\tau\bar{\tau}$ (HOOPERON)
USING DIFF BG SUB.

Today: 2 PARTICLE story ← morality play or TEMPLATE

one of many → ↑ start w/ SIMPLEST one

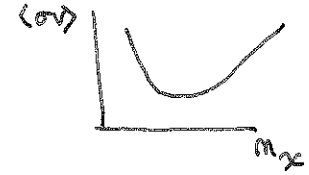
↑ QUANTIFY: DM INTERACTION STRUCTURE
⇒ DIRECT DETECTION (eg LUX)
⇒ COLLIDER (LHC, LEP)

## COMPLIMENTARITY once again

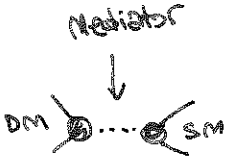
$\langle \sigma v \rangle = a + b v^2 + \cdots$ ← v small today

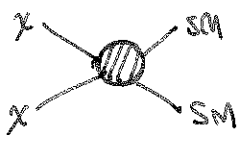
S-wave P-wave

for γ ray src → INDIRECT DET & RELIC AB. low E.

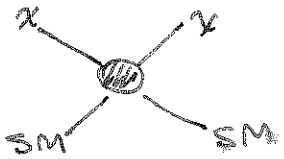



MONO-STUFF ALSO MEDIATOR PRODUCTION!

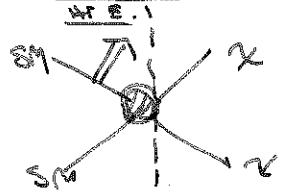


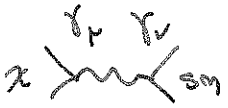




DIRECT DET low E.

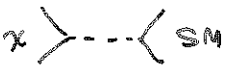



COLLIDER hi E.




VECTOR — S-wave — S-wave (SPIN INDEP OP.) (→ big)




SCALAR — P-wave — S-WAVE


PSEUDO. — S-wave — P-wave

↑ gives γ ray sig → ↑ SUPPRESSED DIR. DET.

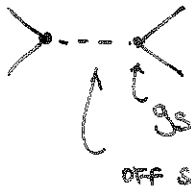

PSEUDOSCALAR — S-WAVE — P-WAVE

↑ the toy model in this paper

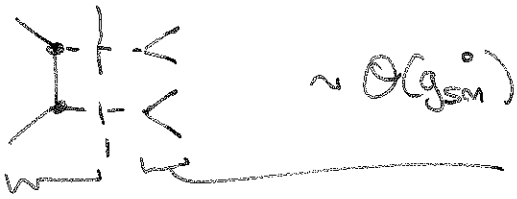
# An aside on current work

LIGHT MEDIATORS ($m < m_{DM}$)

then:



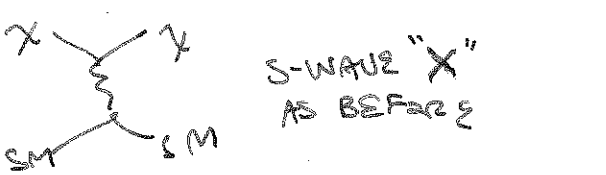
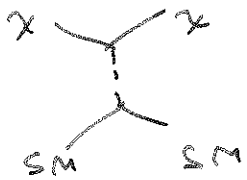

$\sim g_{SM}$



$\sim \mathcal{O}(g_{SM}^0)$

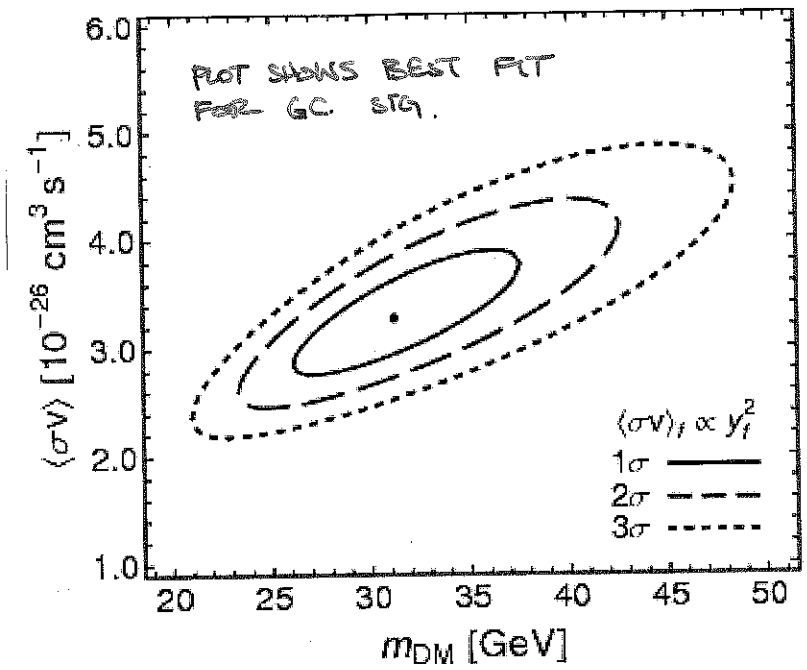
this comes 'for free'

because we're really just probing this.

| INDIRECT | DIRECT |
|---|---|
|  P-WAVE ✗ SCALAR | |
|  P-WAVE ✗ PSEUDO | |
|  S-WAVE | DIRECT DET STILL FROM 1 MEDIATOR EXCHANGE!  S-WAVE "✗" AS BEFORE |
|  S-WAVE PSEUDO |  P-WAVE |


$M_\chi = 90$ GeV ← very different from usual predictions

# Relic Abundance




← Target (MISTAKE IN PAPER)

← TARGET IF MAJORANA

$$\langle\sigma v\rangle = \frac{3}{8\pi} \frac{\overbrace{6}^{\#\text{ COLORS}} \; y_f^2 \, g_{DM}^2 \, m_x^2}{(m_a^2 - 4m_x^2)^2 + m_a^2\Gamma_a^2} \sqrt{1 - \frac{m_e^2}{m_x^2}}$$

$m_x = 30$ GeV for GAL. CTR.

$y_f$: ASSUME MEDIATOR COUPLES ACCORDING TO YUKAWA (MFU) (UP TO OVERALL RESCALING)

$\Gamma_a$ DET. BY $y_f$ + OVERALL RESCALING but larger if $m_a > 2m_x$ — $b, \bar{x}$ / $\bar{b}, x$

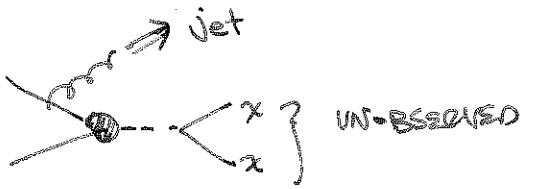
PARAMETERS: $g_{DM}$, $m_a$ (IMPLICITLY ALSO OVERALL STRENGTH OF COUPLING TO SM)

Model building: YOU CAN OVERSHOOT $\langle\sigma v\rangle$ FOR RELIC ABUNDANCE BC ∃ MECHANISMS TO REGENERATE DM

UNDERSHOOT... NEEDS ANNIHILATION TYPE GAMES

OR DISREGARD — eg ASYM DM.

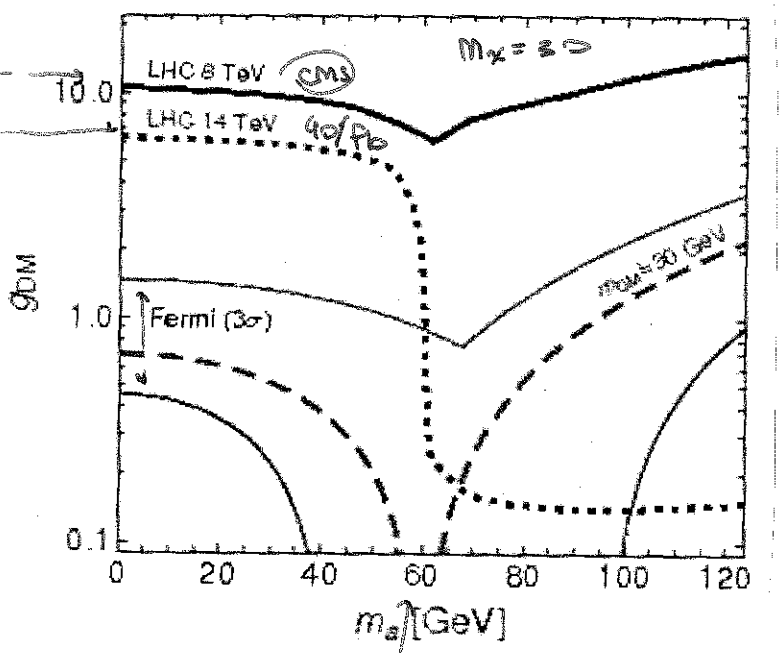
# What kinds of couplings? implic on. LHC.




UN-OBSERVED

CAN DETERMINE $\chi\chi$ $P_T$ FROM JET $P_T$

UPPER BOUNDS FROM MONO JET




VERY LARGE $g_{DM}$ BUT ALSO FOLDS IN SM COUPLING ... SO ACTUALLY ~~GOES DOWN~~ EVEN SMALLER.

MEDIATOR RESONANCE BIG INCREASE IN $\langle \sigma v \rangle$ W/O HAVING TO INCREASE COUPLINGS

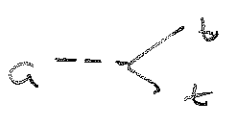
ASSUMP: 14 TeV, $\not{E}_T$ > 400 GeV bin, S/B CONST (SELECTION CUT)

WHY IS 14 SO MUCH BETTER? SEEMS TO BE A FOLD THING ... I SUSPECT YOU HAVE ENOUGH E TO MAKE THE $a$ GO ON-SHELL IN THE REGION $M_a > 2M_\chi$

OTHER COLLIDER BOUNDS ("there are other colliders?")

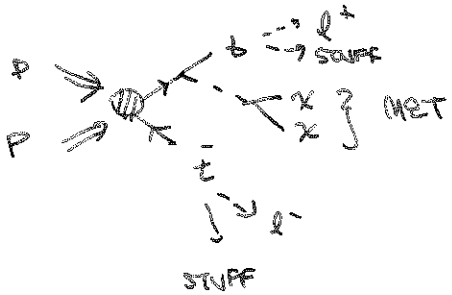
if $a$ couples according to Yukawas $\Leftrightarrow$ couples "to mass"

↑ large coupling to top quark

(but  not kinematically allowed so IRRELEVANT for INDIRECT DET.



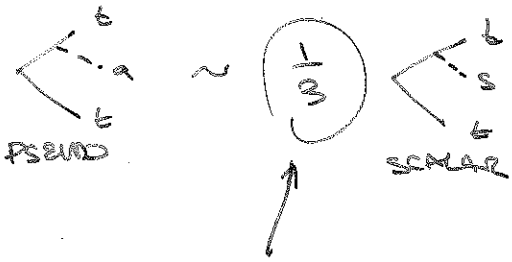
but @ colliders (LHC), PLENTY of energy to PRODUCE TOPS:





CAN DO $M_{T_2}$ SEARCH

↳ LOW SENSITIVITY B/C of LOW ACCEPTANCE (ATLAS $M_{T_2}$)

Remark: 



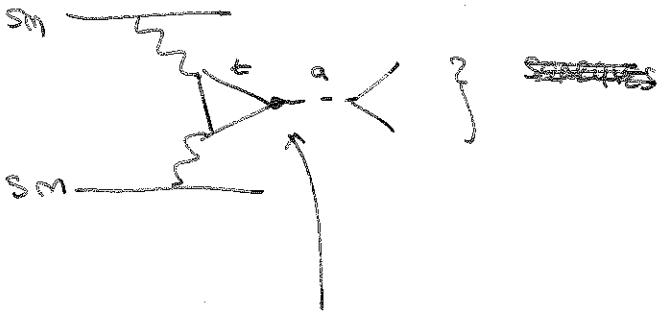
FROM KINEMATICS PS TREATS HELICITIES DIFFERENTLY

$$g: \quad s \to t\bar{t} \sim \left(1 - \frac{4m_t}{m_s}\right)^{3/2}$$

$$a \to t\bar{t} \sim \left(1 - \frac{4m_t}{m_a}\right)^{1/2}$$

## WHAT ABOUT LEP? (& TEVATRON)

Motivation: look @ Higgs searches & swap $h \leftrightarrow a$ (SCALAR / PSEUDO)




~~SEARCHES~~

doesn't explain why $g$ FUSION is ok.

this is apparently very small

↳ $\gamma_5$ in loop conservation of INDICES ✗

ALTERNATELY: think of HIGGS

(HHH) IS LOWEST DIM GAUGE INV OP.
BUT DOES NOT INCLUDE THE GOLDSTONE → NEED HIGHER DIM OP.

("Theorem": PURE PSEUDOSCALAR HAS SUPPRESSED COUPLING TO MASSIVE VECTOR)

(anyone have more insights on this?)

INSTEAD: CONSIDER LHC GLUON FUSION: 


but ATLAS SEARCH FOR EXOTIC HIGGSES, LOOKS @ $\mu\mu$, $\tau\tau$ & CUTS $m_a > 100$ GeV (& background)

eg: $\sigma \times Br(a \to \tau\tau)$ LIMIT IS 20 pb ($m_a = 100$ GeV)

but if $g_{DM} = 0.5$ (hits GC src) MODEL PREDICTS 0.45 pb.

UPSILON BOUNDS: $\Upsilon \to \mu^+\mu^-$ (MED-SM) CONSTRAINTS IF $m_a < 10$ GeV

(can avoid by rescaling $g_{DM}$ or $m_a > 10$ GeV.

## OTHER SEARCHES

- ANTI-PROTONS (BESS-POLAR II)
  - exclude "thermal wimp" that decays to quarks when $M_{DM} = 3\text{-}20$ GeV
    - doesn't affect this model, but I had a nice 12 GeV point w/ gluon decays.
- PAMELA ANTI-PROTONS also don't exclude.

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- CMB : DM annihilation during recomb.
  - but if DM primarily annihilates to heavy quarks or $\tau$, current + proj. limits do not constrain model.

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- $\nu$ flux from DM annih in sun?

  capture cross sec on protons:

$$\sigma_{SD}^{p} \sim 10^{-42}\ \text{cm}^2 \left(\frac{1\text{ GeV}}{m_\chi}\right)^2 \left(\frac{m_{DM}}{1\text{ GeV}}\right)^4 \quad \left.\begin{array}{l} m_{DM} = 100\text{ GeV} \\ m_\chi = 100\text{ MeV} \end{array}\right]$$

  vs. super K: $\lesssim 10^{-38}\ \text{cm}^2$.

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- Fermi dwarf spheroidals — unlikely to have anything to say??

# DIRECT DETECTION

## SPIN-DEPENDENT INTERACTION

→ SUPPRESSED BY MOMENTUM TRANSFER

$$\frac{d\sigma}{dE_R} = \frac{q^4}{m_\chi^2 m_N^2} \cdot \frac{3 g_{an}^2 g_{DM}^2 m_N}{8\pi m_a^4 v^2} \cdot \frac{1}{2J_N+1} S_A(q)$$

- $\frac{d\sigma}{dE_R}$: RECOIL E. ("DETECTION")
- $m_N$: NUCLEUS MASS
- $g_{an}^2 g_{DM}^2$: eff coupling to nucleon
- $v$: Vel.
- $S_A(q)$: SPIN INFO

$q^2 = 2 M_N E_R$

TYPICALLY WORKING @ $E_R \sim 10$ keV, $q \sim 50$ MeV

$\sim \mathcal{O}(10^{-12})$

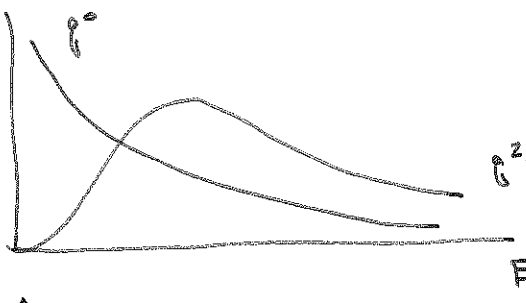
For LZ (LUX-ZEPPELIN):

$$\# \approx 1 \text{ event} \times \left(\frac{g_{DM}}{1}\right)^2 \left(\frac{190 \text{ MeV}}{m_a}\right)^4 \left(\frac{\text{exp.}}{10^7 \text{ kg days}}\right)$$

↑ no hope for $m_a > 10$ GeV.

BUT: this is subtle b/c ASSUMES FORM FACTORS @ ZERO TRANSFER MOMENTUM.

## COMMENTS ON SPIN DEPENDENCE




eg. MDDM 0908.3192

↑ "ADDITIONAL POWERS OF $q$" OVER SPIN INDEP CASE

↑ USUALLY CONSIDER FORM FACTOR @ ZERO MOMENTUM TRANSFER

← not "HELM FORM FACTOR" FOR COHERENCE; ENCODES NUCLEAR RESPONSE.

BUT ACTUALLY WE HAVE A MIN THRESHOLD & THERE CAN BE AN S-WAVE PIECE.

↳ COULD THIS BE AN APPRECIABLE EFFECT?

↓

KATHRYN E. says no, not really (1401.3739)

CAN ALSO CHECK IF SM LOOP EFFECTS MIGHT GIVE ~~[illegible]~~ S-WAVE PIECE THAT'S LARGER THAN SUPPRESSED PIECE → hepc. 1012.5317.

↓

More careful study req'd? BUT SEEMS LIKE NOT A BIG EFFECT.

WHY? BIG CORRECTIONS FROM TARGETS W/ LARGE ANGULAR MOMENTUM
↳ eg IODINE IN CSI(Na)

NOT HEAVY TARGETS LIKE Xe ? Ge: EVEN IF NR RESPONSE IS DIFFERENT BC SINCE MAX RECOIL E IS LOW

↑ 4-50 keV

↑ motivates heavy DM expt?